Appendix F - Fens and bogs

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This account is largely based on material in the 'freshwater and wetlands habitat narrative' (Mainstone et al*. 2016), which can be consulted for further information on these habitats.*

F1. Habitat variation

The variation within the habitats encompassed by the terms 'fens and bogs' is immense, particularly if the transitions to associated habitats such as wet woodland, wet grassland and wet heath are considered. Detailed descriptions of natural (and not-so-natural) wetland habitat features and associated assemblages and species are provided in various sources including McBride *et al.* (2011) for fens, Hawke and Jose (1996) for reedbeds, Brooks and Stoneman (1997) and Lindsay (1995) for bogs and Wheeler *et al.* (1999) for wet woodlands. The National Vegetation Classification (NVC) helps to describe the variation in wetland vegetation types but it is important to remember that at any given site natural wetland mosaics tend to be dynamic and transitional in nature, in both space and time, consisting of a complex and changing pattern of vegetation types.

F2. Factors affecting ecological position in the landscape

Terrestrial wetland habitats are naturally formed by the flow and retention of water in the landscape, The diversity of wetland types is generated by variation in the types of hydrological pathway (surface, sub-surface and groundwater, dependent on landscape geology and topography), the magnitude and regularity of water supply, water chemistry and nutrient status (products of the journey of water through soils and rocks) and, finally, the climatological and biological influences (e.g. grazing/browsing pressure) on the ensuing vegetation. The variety of landform and climate across a landscape naturally forms a mosaic of terrestrial wetland habitats of various degrees of wetness and hydrochemistry, interspersed with running and standing open waters of different types and sizes.

Important landforms for wetland habitats include:

- valley heads where hydrological pathways converge to form valley mires;
- the interface between valley sides and river floodplains where springlines form;
- depressions in the landscape that give rise to open waters, which can be succeeded by basin fens, and in some cases ultimately raised bogs;
- glacial deposits in flatter landscapes generating microtopographical variation that gives rise to gradients of wetness,
- river floodplains where the erosional and depositional activity of the river creates a complex microtopography, generating different periodicities of inundation by floods and nutrient gradients across the floodplain;
- outcropping; bedrock features that cut across hydrological pathways and can create water accumulation anywhere in the landscape.
- upland plateaus of low permeability and high rainfall giving rise to blanket bog.

Superimposed on this characterisation of wetland habitats are various dynamic processes that dictate that wetland habitats change or shift in the landscape to varying degrees. Natural annual weather variation and longer term climate variation can create reductions or increases in wetness at any given location, with either short- or long-term consequences for the assemblages and individual species present. Processes such as natural erosion, or the formation and decay of woody vegetation, or the development of *Sphagnum* carpets all generate changes in the level of water retention and hydraulic energy at any given point in the landscape, and can result in either gradual or step-changes in hydrological conditions and therefore biological assemblages.

A good example of this dynamism is the influence of abiotic and biotic controls on headwater mire systems. Outcropping bed rock cutting across a hydrological pathway may create long-term controls on water retention, generating quite stable conditions for the development of mire vegetation until erosion of the bedrock generates a drop in water retention and increase in hydraulic energy, and a consequent shift from mire to stream habitat. Alternatively, the growth of trees in the valley mire may provide short term stability in water retentiveness, caused by the trapping of vegetation within tree root systems and fallen boughs and trunks. Decay of this material can result in a drop in water retention and increase in hydraulic energy, again creating a shift from mire to stream habitat. Cycles of woody growth and decay of this type can create a cycling between mire and stream habitat at any one point in a headwater valley system, with mire/stream transitions migrating up and down the valley.

Natural vegetation succession creates a further level of dynamism in the wetland habitat mosaic. Standing open water habitats naturally gradually succeed into swamp, and then onto fen and finally rain-fed bog or fen woodland, unless prevented from doing so by site-specific environmental conditions or the action of biological factors (grazing or trampling by animals). Again, the specifics of water supply/retention and water chemistry dictate the path of succession through different wetland habitat types, although succession 'end-points' are not always predictable or even necessarily permanent.

F3. Ecological function and relationships

The largest, most diverse and generally highest quality wetlands occur in large sites as part of relatively unmodified landscapes in transition to and in mosaics with rivers, lakes, forest, grasslands and heaths. In the most part, in England, these occur in the uplands and in a few exceptional lowland settings such as the New Forest, although none is truly unmodified and free from human intervention in the form of drainage, stock grazing and/or recreational uses. In these upland systems, natural hydrological processes are relatively unconstrained, and dynamic change is more likely than in the highly constrained lowlands.

The absence of naturally functioning wetland systems in England can act as obstacle to understanding their natural biological patterns, and consequently to developing restoration strategies that aim to restore the natural hydrological processes that give rise to them. Models are provided however by relatively natural systems such as the Biebzra river floodplain in Poland (e.g. Wassen *et al.* 2002), and also less modified British examples, such as the Insh Marshes in Scotland, and the Norfolk Broads, which although historically highly modified by peat digging have been allowed to develop hydroserally and retain some natural features (e.g. Pallis 1911).

Such unmodified floodplain systems tend to show a strong nutrient gradient across the floodplain, with higher natural nutrient availability in frequently flooded areas closer to the river, and decreasing nutrient availability as the floodplain rises towards the valley sides. Species predominating in the wet, nutrient-rich conditions are tall vigorous grasses such as common reed *Phragmites australis* and reed sweet-grass *Glyceria maxima*. These situations provide the natural setting for the large reedbeds that have been lost from the landscape, along with many of their characteristic species. The vegetation is generally species poor but highly productive. These areas provide habitat for valued species such as bittern *Botaurus stellaris* and marsh harrier *Circus aeruginosus*. Areas closer to the river also tend to experience greater fluctuations in water level than those towards the back of the floodplain.

Further from the river, conditions become gradually less nutrient-enriched and the characteristic fen vegetation supports a wider range of tall-herb species, for example common meadow-rue *Thalictrum flavum* and milk-parsley *Thyselium palustre*, the food plant of the swallowtail butterfly. With low levels of vegetation control, i.e. limited grazing and cutting, fen woodland would be a major component of vegetation cover in floodplains

F3.1 Valley sides and headwaters

At the valley sides, the water levels tend to be more stable, but the water supply may be quite different; only small amounts of river floodwater, with its nutrient-rich sediments and dissolved salts, reaches this area, and low-nutrient groundwater emerging from the base of valley slopes as springs and seepages can form a significant source of water. The chemical nature of the groundwater will vary depending on aquifer geology. In areas with calcareous geology, the vegetation around springs and seepages can be very species-rich. This is characterised by a diversity of low growing sedges, including dioecious sedge *Carex dioica* and flat sedge *Blysmus compressus* a Section 41 species, growing in a carpet of 'brown mosses' such as *Palustriella commutata*, *Campylium stellatum* and *Scorpidium scorpiodes*. These are accompanied by a rich variety of broadleaved plants, including grass-of-Parnassus *Parnassia palustris*, marsh valerian *Valeriana dioica* and butterwort *Pinguicula vulgaris*.

This habitat is extremely rich in invertebrates, including several threatened snail species, including the Habitats Directive Annex II species Geyer's whorl snail *Vertigo geyeri*, and soldier flies, including the very rare clubbed general *Stratiomys chamaeleon*. For many of these species the open, permanently saturated mossy conditions are critical to their survival, and loss of saturation through drainage and nutrient enrichment leading to shading of moss carpet by tall vascular plants is very damaging.

Where the emerging groundwater is more acidic, species numbers may be smaller, but a distinctive community of plants and animals would still be present. In areas with more complex geology, groundwater may emerge from acidic geology overlying basic rocks, giving rise to a whole series of gradients of water tables and water chemistry and biological transitions. This still occurs in a several sites in East Anglian valleys, although many such transitions and their characteristic species have been lost through drainage, groundwater abstraction and nutrient enrichment of the groundwaters. Often, it is the species that are especially characteristic of transitions that are most sensitive to human modifications, which in general lead to simplification of complex abiotic conditions and consequently simpler and less diverse biological patterns.

These groundwater-fed wetlands would occur throughout landscapes in which groundwater emerges from bedrock or drift geology in the form of springs and seepages. Many such features have been lost from the lowlands, and are now best seen in a relatively natural state in upland hill landscapes. Very similar vegetation occurs in these landscapes because the ecohydrological and hydrochemical conditions are essentially the same as in lowland counterparts, although the groundwater emerging in upland situations is much less likely to have been enriched with nitrogen or phosphorus through intensive land uses than groundwater from lowland aquifers. Consequently many of the species lost from lowland groundwater-fed fens (e.g. the Schedule 8 moss *Hamatocaulis vernicosus,* shown in Figure F1, and common butterwort) still occur in the uplands, and are sometimes erroneously regarded as 'upland' species by those unaware of the loss of such species in the lowlands where they are unable to survive in nutrient-enriched conditions.

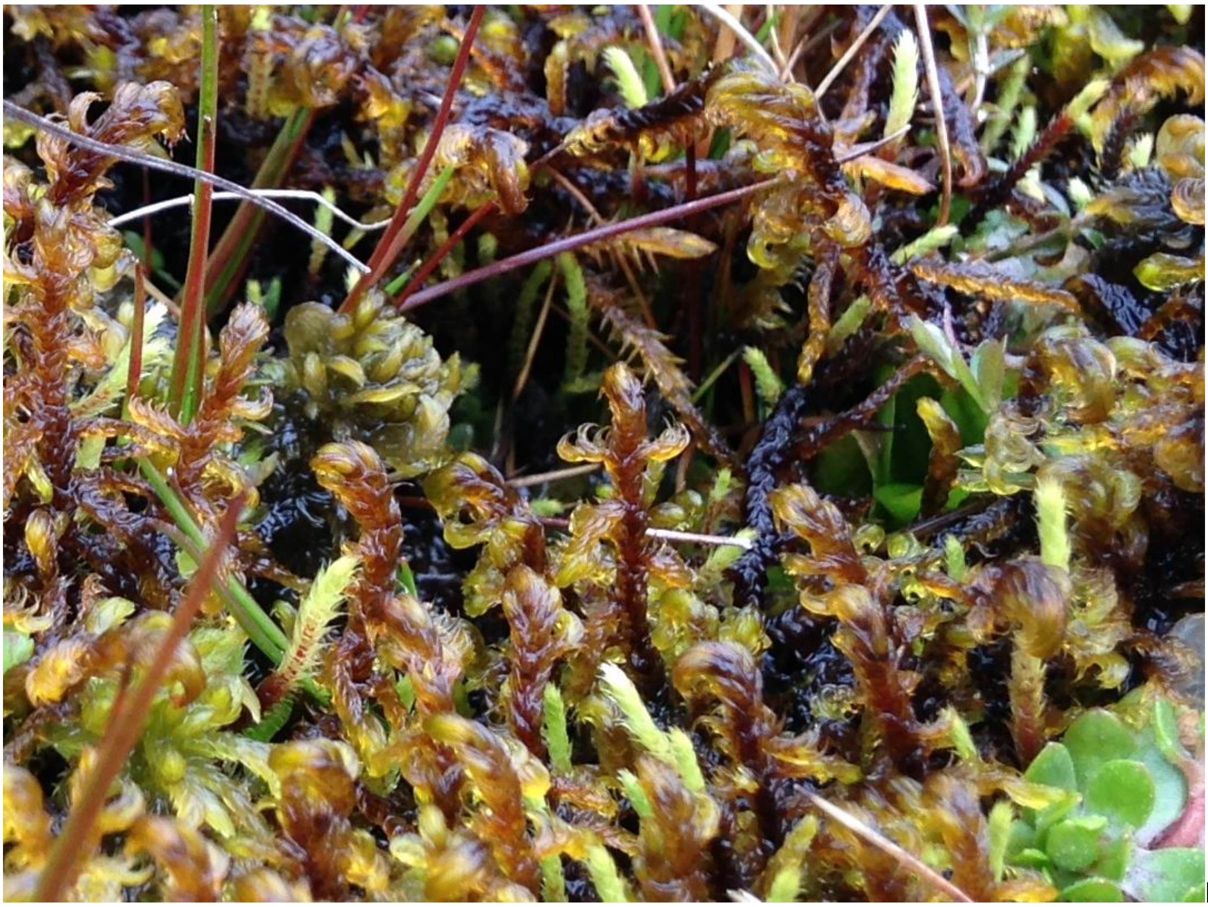

Figure F1. *Hamatocaulis vernicosus* in moss-rich upland neutral flush. The patterning and high diversity of plants at such a small-scale is immediately lost following nutrient enrichment, hence the loss of such species from English lowlands.

Between the nutrient-rich tall fen and valley side fens various other wetlands develop, including pools and runnels taking water from higher ground and groundwater outflow across the floodplain, as well as various wet woodlands, fens and fen meadows and seasonally flooded grasslands. The exact configuration and species composition depend on the character of the river, surrounding geology and climate.

In certain situations, raised bogs have developed in floodplains. Following a classic hydroseral trajectory, rain-fed bog vegetation develops on top of deep peat following millennia of accumulation of plant material in saturated conditions. Floodplain bogs can develop from the terrestrialisation of a single lake basin, or over more undulating terrain in which a number of small basins coalesce to form a single dome (Lindsay 1995).

Raised bogs occurred more widely in England than is generally recognised, in a range of topographical situations, including basins and coastal plains, in addition to river floodplains. There is evidence for bog development in most parts of the country including the south east, for example, the Arun valley in Sussex and the East Anglian Fens. The best remaining examples of raised bogs in river valleys are found in Cumbria, where for example in the Duddon Valley and the Lyth Valley, domes of peat that still support bog vegetation survive in otherwise drained and modified floodplains. Raised bog can also develop in other landscape contexts, particularly in basins and in coastal plains over estuarine sediments.

Unmodified raised bogs, of which there are none in England, have a unique and structural and functional integrity, comprising numerous structural components and different types of wetland, including not only ombrotrophic bog dominated by numerous species of *Sphagnum* moss and dwarf shrubs, but also dystrophic pools, flowtracks within the bog, and around the margins (or lagg) various wetlands, their character determined by surrounding topography and the hydrochemistry of the water draining into the bog (Figure F2).

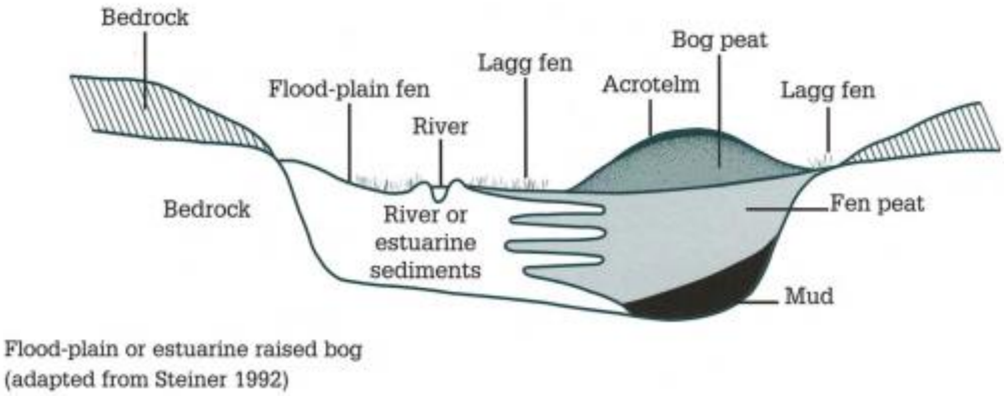

Figure F2 Conceptual cross-section of a floodplain showing raised bog development over accumulated fen peat and lake muds (from Lindsay, 1995).

The integrity of all the separate features of the bog is co-dependent and relies on an intact hydrological regime across the whole system including the lagg fen, where water draining from the bog meets water draining from the surrounding landscape (as illustrated in Figure F3). The character of the lagg is strongly influenced by the surrounding landscape and its geology, as illustrated in Figure F4 - calcareous water emerging from Carboniferous limestone has generated an environment in which species of base-rich conditions occur in close proximity to species reliant on the very acidic conditions of the bog surface. At a larger, or *macrotope*, scale individual peat bodies may continue to grow, spread and coalesce, coating entire landscapes in peat.

Figure F3. Tarn Moss, North Yorkshire. Showing relatively natural bog-edge with base-rich lagg fen in foreground, bog in background, natural (i.e. unditched) lagg stream, uninterrupted transitions.

Undisturbed bogs typically have an almost continuous carpet of *Sphagnum* species, creating a very acid and nutrient-poor environment. Within this are rooted vascular plants such as cross-leaved heath *Erica tetralix*, the cotton-grasses *Eriophorum angustifolium and E. vaginatum*, cranberry *Vaccinium oxycoccus* and various sundew *Drosera* species. Unmodified bogs exhibit a very distinct natural patterning, with different species occurring in different positions relative to the water table (Figure F5). The degree of patterning varies according to climate and slope, with the most complex patterning in the wetter north and west of England on flat sites and least pronounced in the drier parts of the range.

The three native sundews demonstrate the variety of niches within this structural complex, with round-leaved sundew *D. rotundifolia* tending to occur on higher, drier hummocks, great sundew *D. anglica* on the wetter low ridge/*Sphagnum* lawns, and oblong-leaved sundew *D. intermedia* on the edge of pools and bare, exposed peat in hollows. In an unmodified bog, the water table tends to be highly stable, allowing these patterns to persist for decades or more. This microtopographical variation and the presence of stable niches affords great resilience to bogs in the face of changes in climate, as those species characteristic of wetter conditions increase in wet periods and those of the hummock tops prevail in drier periods. Modification to the system results in loss of some or all of these niches and their associated species, leaving a much less resilient system.

Figure F4. Base-rich fen with globeflower in lagg of Tarn Moss with willow scrub adding structural complexity.

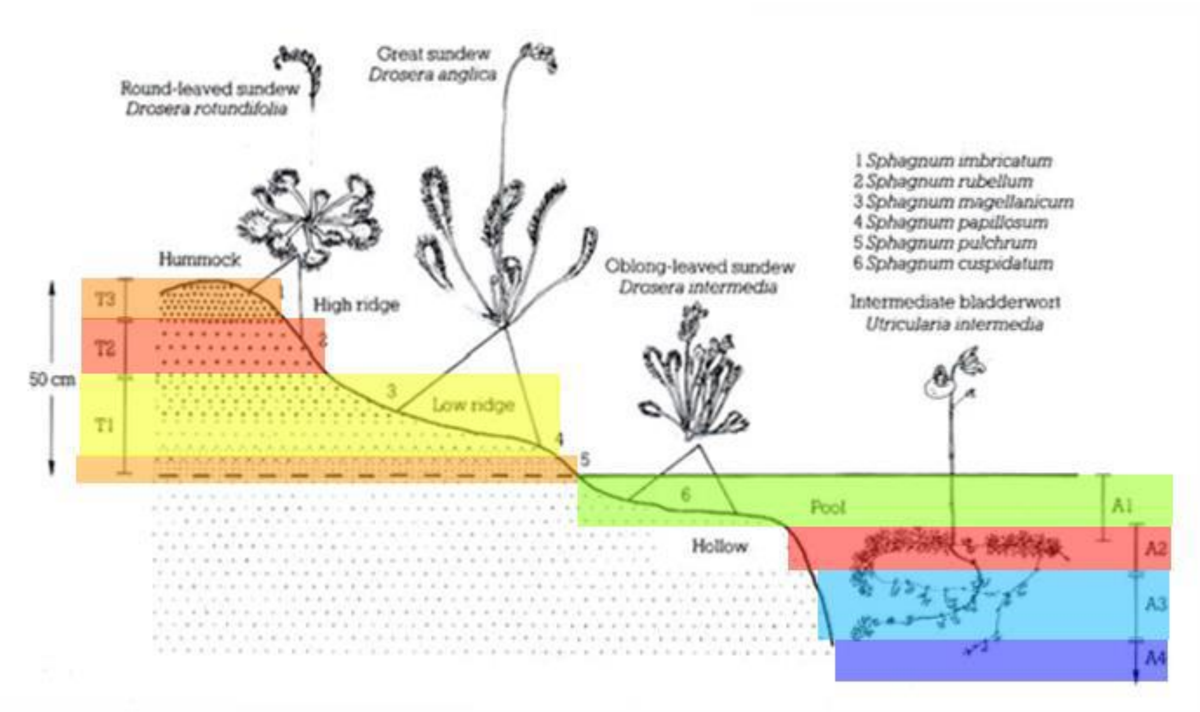

Figure F5. Small-scale vertical zonation within a bog – position of species determined by elevation relative to water table (From Lindsay *et al*., 2014).

F4. Current levels of natural function

A wide range of human activities, past and present, have damaged and changed the natural wetland habitat resource. The most fundamental impacts relate to modifications to natural hydrology and hydrochemistry, which have brought about great change in the extent and types of wetlands in the landscape. Perhaps of greatest note is the loss of large, complex wetland habitat mosaics, for example, those that would have occurred in floodplains and the lower reaches of larger rivers, with the loss of many species, particularly larger species such as bittern and spoonbill.

The absence of unmodified raised bogs in England is a legacy of many modifications, notably industrial milling of peat, which necessitated deep drainage of bogs in order to extract the material. In addition, large areas of peatland in northwest England and in the East Anglian Fens have been deep drained and cultivated to provide highly productive farmland. These activities have destroyed the wetlands but in other areas, although bogs may not have been exploited to extinction, they have been severely modified by cutting of peat around the edges and agricultural 'claim' through drainage of lagg areas and previously cut edges. This may leave areas of bog vegetation surviving in the centre of dome, but the hydrology of the whole is severely compromised, with the loss of much of the diversity of microtopography and hence the biodiversity.

The hydrology of most, if not all, English terrestrial wetlands has been modified by historic drainage both within sites and in the surrounding environment, eliminating wetlands from much of the landscape. Many of the declines in wetland wildlife can be directly related to drainage schemes (Purseglove 1988). Different drainage practices in different types of landscape have generated distinctive impacts, including the following.

- Moorland gripping has resulted in the loss of active blanket peat, with its complex distinctive and diverse habitat mosaic of dystrophic pools, *Sphagnum*-dominated bog, drier areas with ericaceous vegetation, and bog-stream transitions.
- The digging of catch-drains in the margins of floodplains, along with associated underdrainage of the lower valley sides, has resulted in the loss of flush habitat around valleyside springs and the dewatering and loss of fen vegetation at the valleyside/floodplain interface, (e.g. Gardiner 2017).
- The underdrainage and ditching of springs and streams in headwater valleys have resulted in the loss or degradation of valley mires and natural mire/stream transitions.

- Deepening and straightening of rivers, and drainage of their floodplains, has resulted in the loss of the complex abiotic gradients across the floodplains and much of the associated biota. Remnants of wetland wildlife persist in drainage ditches in some floodplains, along with some species that may have benefited from lower intensity agricultural practices in the drained landscape, such as lapwing. The degree of modification of most floodplains in England now though has resulted in even the species that could live alongside ‘traditional’ agriculture suffering very severe declines.

The hydrochemical environment of most lowland wetlands has also been significantly altered from a natural reference point, through changes to both hydrological function, resulting in altered balance of water supply (e.g. reduction in ratio of calcareous groundwater:surface water as a result of groundwater abstraction in chalk aquifers) and nutrient availability (largely increasing rather than decreasing) as a result of activities in the catchment, such as intensive agriculture and urban run-off.

Superimposed on these modifications to abiotic conditions are activities relating to on-site vegetation management, including cropping, woodland planting (e.g. widespread planting of poplars on fens in 1970s), often with associated drainage and agricultural intensification.

The biological response has been one of wholesale simplification of plant and animal communities and loss of many species from large areas of the country, particularly those of low-nutrient and very wet conditions, including species now extinct in England such as Rannoch-rush (*Scheuchzeria palustris*), or suffering significant very declines, e.g. *Drosera anglica*.

The situation in upland fens is less severe given the generally lower intensity of land use, however, upland wetlands have been and continue to be damaged and altered by various pressures including drainage, burning and atmospheric nutrient deposition. Grazing, which maintains open fen conditions over much of the uplands and upland fringe, can however have negative impacts. It is not uncommon for upland fens to have been severely damaged by heavy stock grazing and trampling, often resulting in proliferation of soft rush and loss of *Sphagnum* and other bryophytes that perform such an important role in the ecological function (as well as provision of other services, such as water retention) of these systems.

Clearly, many of our valued fens have been subject to some degree of modification from a truly natural state, indeed it is likely that many herbaceous fen ‘vegetation types’ that we recognise did not really occur before human clearance of woodland. Many of the characteristic species of the fens would have occurred within natural systems in swamp woodland or very wet open areas around groundwater upwellings and seepages (Figure F7), and in areas of windthrown trees (Figure F8). For example, the extensive very rich fens of the Broads have developed under a system of low-key exploitation, with the characteristic species-rich tall herb fens cut on rotation for reed, or ‘litter’, or ‘sedge’ (*Cladium mariscus*), to be used for roofing materials and animal fodder, and peat digging for fuel created shallow pools. Their current extent and configuration is, therefore, to a large degree the result of cultural management, but crucially, within a context of relatively minor modification of abiotic processes, i.e. still very wet and relatively low/near-natural nutrient status.

As the fen products became less economically important, the fens were either drained and agricultural production intensified, leading to loss of many or all wetland species, or left to return to fen woodland. Some of the open fen species would survive in this woodland, but many of the obligate species of wet open habitats did not survive, as the natural dynamism and diversity of the floodplains that once created a multiplicity of niches, including the narrow niches required by these species, had been lost to river engineering, floodplain drainage, nutrient enrichment and capture of the groundwater flows from the valley sides in ‘catchwater’ drains.

Figure F7. *Sparganium natans* (VU on England Red List) growing in a natural pool in fen woodland.

Figure F8. Windthrow creating open pools in bog woodland.

An expert judgement of the habitat resource in relation to natural function is summarised in Tables F1 and F2. An explanation is given below of the way in which the five pillars of natural function outlined in the main report (Section 3) have been interpreted in respect of fen and bog habitats. Note that the structure of natural function used in this report does not quite fit the way in which such function is typically portrayed in freshwater habitats (see Mainstone *et al*. 2016), because the structure has to be applicable to all habitats considered by this report. It does however suffice for the purposes of providing a more integrated evaluation of habitats in respect of natural function.

- ***Hydrology* –** this is interpreted as hydrological impacts from abstraction, land drainage and water impoundment and diversion, and includes hydrochemical impacts not associated with nutrient enrichment.
- ***Nutrient status* –** for open fen and bog habitats this is interpreted as the supply of macronutrients (phosphorus, nitrogen and potassium) in the water, atmospheric deposition and in the wetland substrate, including the additional adverse effects of the additional productivity. Also included here are other impacts on natural nutrient and chemical status such as acidification and toxic pollution, which can be major issues in the wetland environment.
- ***Soil/sediment processes* –** for fens and bogs this is intimately linked to hydrological and geological processes, and has been interpreted here primarily as the condition of peat, e.g. active vs. non-active and degraded, but also considers other depositional processes, such as tufa-formation in around calcareous groundwater outflows and deposition of material in fluvial flooding.
- ***Vegetation controls* –** this is interpreted as management of herbaceous and woody vegetation that has a detrimental effect on sustaining characteristic habitat mosaics formed by natural processes. This includes both over-management and artificial cessation of any grazing, even at natural levels, due to fencing off or abandonment of wetlands.
- ***Species composition* –** this is interpreted as effects on composition beyond those caused by impacts on the other four pillars above, relating to the impacts of non-native species.

Table F1. Indicative levels of natural function in the raised bog resource.

State of naturalness	Prevalence of state within the habitat resource				
	Hydrology	**Nutrients**	**Soil/sediment**	**Vegetation control**	**Species composition**
Good	Low	Low	Low	Low	Low
Intermediate	Low	Moderate	Low	Moderate	Moderate
Poor	High	Moderate	High	High	High
Confidence	*Moderate*	*Moderate*	*Moderate*	*Moderate*	*Moderate*
Comments	*No English bog has unmodified hydrology. Even the best sites continue to suffer from drainage.*	*Aerial deposition of N compounds. Release of nutrients following peat desiccation/oxidation. Fertilisation on drained peat; and marginal watercourses and artificial drain water often nutrient enriched by off-site activities.*	*Linked to hydrology – drainage results in a) loss of active bog →cessation of peat accumulation; b) oxidation and physical erosion of dry peat.*	*This is closely linked to hydrology, as drainage often results in proliferation of woody species, compounding the direct effects of drainage. Many drained bogs have been afforested. In unmodified bogs, the saturated and very low nutrient, acidic conditions limit biomass production, and vigour of woody species.*	*Rhododendron, non-native conifers planted/invaded – dry/drained sites more at risk. Pitcher plant a problem invader on some sites*

Table F2. Indicative levels of natural function in the fen resource.

State of naturalness	Prevalence of state within the habitat resource				
	Hydrology	**Nutrients**	**Soil/sediment**	**Vegetation control**	**Species composition**
Good	Low	Low	Low	Moderate	Moderate
Intermediate	Moderate	HIgh	Moderate	Moderate	Moderate
Poor	High	Moderate	High	Moderate	Low
Confidence	*Low*	*Low*	*Low*	*Low*	*Low*
Comments	*All with some degree of drainage impact. Some affected by groundwater abstractions. A few fens 'created' by altered hydrology, e.g. lake drainage, hydrological barriers impounding water.*	*Point and diffuse water pollution; atmospheric N deposition likely to be affecting many fens.*	*Drainage likely to have affected rate peat formation; groundwater abstraction may affect tufa formation. Removal of interaction with rivers in floodplains limits natural sediment deposition patterns.*	*Most fens would support fen woodland in the absence of grazing/herbivory or cutting, although the wettest fens more likely to remain relatively unwooded. Strong interactions with hydrology and nutrients.*	*Issues with skunk cabbage, Himalayan balsam, Crassula & competitive exclusion effects on native species.*

F5. Scope for restoration of natural function

A summary of the scope for restoration is given in Tables F3 and F4. Given the enormous scale of the modification of fen and bog habitat in the lowlands particularly, but also in the uplands, there is clearly enormous scope in principle for restoration of natural hydrological processes in these habitats and in the landscapes in which they sit. In practice, however, there can be many constraints on achieving this aim, including infrastructure, neighbouring high grade agricultural land and habitations, that may be adversely affected by re-naturalisation. In addition, even in situations in which there are no obvious physical or socio-economic constraints, long-term eutrophication of surface, and in particular, ground-waters, may severely constrain the ambition in the short-term. These can make the hydrological restoration of terrestrial wetland systems both complex and expensive.

Hydrological restoration can, however, contribute to long-term sustainability, for example, with regards to climate change adaptation. It can also reduce other stressors in the landscape such as the impacts of air pollution, water pollution and habitat fragmentation. Landscape-scale management with sufficiently long-term objectives can help integrate hydrological restoration with other actions for biodiversity, climate change adaptation and enhanced ecosystem services.

Restoration of natural hydrological processes in areas such as the East Anglian Fens, an intensively drained area important for food production, is constrained by the need for ongoing drainage. In these areas some recent restoration initiatives to increase the populations of large appealing species, e.g. bittern, have been very successful, although the model employed has not been to restore large naturally functioning dynamic wetlands but generally to engineer conditions required by the species. While this may work as a short-term fix to prevent species extinctions, or be the best option in areas with significant constraints, in the longer-term restoration of all (or at least more of) the ecohydrological components of this and other landscapes are needed to restore more diverse and resilient wetlands supporting the species characteristic of the natural conditions of the locality, rather than pre-determined vegetation types in artificially maintained reserves.

Generating a reference hydrological template for the landscape (to understand how habitat mosaics would occur naturally) provides an assessment of the potential for habitat restoration and re-creation within a site and in the wider catchment. For wetlands, the work of Wheeler *et al*. (2009) is particularly helpful in understanding the ecohydrological development and history of sites and landscapes. Historical biological records can also reveal likely conditions in times when larger more naturally functioning wetlands were still present. A useful example of this approach is Meade (2011) for the Lyth Valley in Cumbria.

This template subsequently informs a decision-making process for setting appropriate hydrological ambition for sites. The appropriate long-term hydrological ambition should be embedded in the conservation objectives of individual wildlife sites to provide clarity to stakeholders and partners, and to ensure that the available mechanisms work towards these targets. Whilst many physical and hydrological modifications are effectively immovable (e.g. flood defences protecting urban areas), others have the potential to be reversed if a sufficiently strategic and long-term view is taken.

Hydrological restoration potential must be assessed at a landscape or catchment scale, taking a sufficiently long-term view with respect to what habitats could develop in a hydrologically-restored landscape (and taking into account constraints such as climate change, natural variability and other strategic conservation objectives). It will be necessary to consider constraints and assess feasibility and cost of overcoming these when translating a long-term vision into appropriate hydrological targets in a coordinated manner.

What can be realised in practice, however, will be highly site-specific, and will vary between different types of landscape. In contrast to the Fens example, restoration of fen and bogs in headwater catchments directly affects relatively little land and has benefits for all downstream freshwater habitat, as well as downstream water management. Also often in its favour is the relatively high water quality in headwaters, leading to the development of more natural biological assemblages. However, at least some aspects of natural function can be restored in larger floodplains, particularly those with relatively little development. Restoration of valleyside springlines, to restore runnels, streams and pools amongst restored fen, has great potential even where restoring full natural hydrological function, e.g. main river restoration (river movement, river-floodplain interaction) is difficult.

In focusing on restoration of natural processes, allowances will need to be made for the re-positioning of high-value existing habitats, for example floodplain meadow, and associated species within the landscape according to restored hydrological processes, factoring in adequate connectivity to allow species to sustain viable populations, and time to allow movement of species to newly suitable conditions. The assessment of the potential for restoring natural hydrological functioning may result in identifying potential for restoring habitats that are currently not present.

Table F3. Desirability and scope for restoring more natural function in the raised bog resource.

	Hydrology	Nutrients	Soil/ sediment	Vegetation control	Species composition
Desirability	Yes	Yes	Yes	In part	Yes
Comments	Needed to restore water table to surface across peat expanse, & restore natural hydrological transitions between mire expanse, mire margins and transitions between bog and surrounding landscape, including natural pools and water courses on and around bog.	Needed to restore full natural range of marginal habitats, low nutrient environment in bog centre.	Needed to restore peat-forming conditions.	In restoration phase woody vegetation removal necessary to reduce evapotranspiration on already desiccated surface, and possibly grazing of rank herbaceous vegetation. In restored state grazing of mire margins/lagg will maintain open wetland conditions if desired. Vegetation control (grazing) may not be necessary on mire expanse.	Needed to restore natural species assemblages.
Conservation constraints	Few. Main issue likely to be loss of any habitat developed on drained peat and associated species.	Natural nutrient levels are generally a shared conservation goal across all habitats and species	Strongly linked to restoration of hydrology.	Removal of trees and associated species may be contentious – may be scope for adjacent compensatory woodland development.	No biodiversity conflicts.

Table F4. Desirability and scope for restoring more natural function in the fen resource.

	Hydrology	Nutrients	Soil/ sediment	Vegetation control	Species composition
Desirability	Yes	Yes	Yes	Yes	Yes
Comments	To re-establish natural range of hydrological conditions across fens, including transitions between wetter/drier, acid/base-rich & naturally mediated nutrient gradients. Also regenerate natural open water features within sites. Greatest scope in uplands.	Needed to restore characteristic assemblages of local hydrogeology	Needed to restore peat-forming conditions.	Restoration of grazing or cutting widely required in lowland fens to prevent complete loss of open fen to woodland. Vegetation control (grazing or cutting) may not be necessary on very wettest parts of fens, e.g. quaking fen.	Needed to restore natural species assemblages.
Conservation constraints	Unnaturally high nutrient status of some waters may constrain full hydrological restoration if high value, low nutrient-conditions within site jeopardised. More likely to be constraint in lowlands. May be some loss of drier habitats, or at least shifts in species distribution/frequency.	Natural nutrient levels are generally a shared conservation goal across all habitats and species	Strongly linked to restoration of hydrology.	Removal of trees and associated species may be contentious – may be scope for adjacent compensatory woodland development. Wet woodland development on some sites with little scope to restore high quality fen may be preferred option for biodiversity.	No biodiversity conflicts.

F6. Provision of habitat for particular species

F6.1 Invertebrates

Pantheon recognises 1,114 species associated with fens and bogs. Water level fluctuations are not usually significant, or at least, when they do occur, the substrate rarely dries out completely. Consequently this assemblage type is dominant on wet peat.

Invertebrates of peatlands are associated with the resources and microhabitats present. Factors such as nutrient status, water chemistry and vegetation succession play a big role in determining these microhabitats. *Sphagnum* lawns develop in nutrient poor, acidic conditions; wet woodlands and scrub develop where grazing is kept in check; peaty ponds are present in saturated habitats etc. The key features, along with the number of associated species, are outlined in Table F5.

Table F5. Key habitat types and associated numbers of invertebrate species.

Key feature	Number of associated species	% of the total number of species associated with peatland
wetland vegetation: including stands of Carex, Phragmites, Phalaris, Typha etc	348	31
ponds within peatlands	374	34
aquatic vegetation within ponds	232	21
wet woodland	281	25
wet/damp peat	269	21
Sphagnum/moss lawns	185	17
Scrub	Unknown	Unknown

F6.2 Lower plants

Bogs are one of the few forms of vegetation where bryophytes comprise the main structural component, with species of *Sphagnum* moss often dominant over wide areas, and the hummocks, hollows and pools providing habitat niches for different species. In very wet hollows and bog pools *Sphagnum cuspidatum* and *S. denticulatum* are frequent, and the Nationally Scarce *Sphagnum pulchrum* occurs in in wet hollows in undisturbed bogs, where it may form extensive and colourful orange-yellow carpets. The main hummock-forming species now are *S. papillosum* and *S. capillifolium*, although before the Industrial Revolution *S. austinii* was one of the major hummock and peat-forming mosses in bogs, but this is now very rare in England. Amongst these, species such as *S. magellanicum*, *S. palustre, S. tenellum* and *S. fallax* also occur.

Other mosses in acidic bogs include several species of *Campylopus* and *Dicranum*, together with pleurocarpous mosses that also occur on heathland, such as *Hypnum jutlandicum* and *Pleurozium schreberi*. Liverworts characteristic of bogs include *Odontoschisma sphagni* and small species of *Cephalozia*, *Cephaloziella* and *Kurzia*. The liverworts *Pallavicinia lyellii* and *Jamesoniella undulifolia,* together with the moss *Dicranum bergeri* (previously known as *D. undulatum*), are all Endangered Section 41 bog species.

Base-rich fens are of more limited extent than acidic bogs, for example occurring where there is mineral-rich flushing within bogs or as hillside flushes. However they may be more extensive around water bodies that are sourced from base-rich catchments, and may be frequent in limestone regions.

In fens chemically transitional between acidic bogs and base-rich fen, bog *Sphagnum* mosses become less frequent, and different species of *Sphagnum* such as *S. inundatum*, *S. contortum* and *S. teres* occur, together with mosses such as *Bryum pseudotriquetrum*, *Philonotis fontana* and *Plagiomnium ellipticum*. The 'brown mosses', a term used for a group of pleurocarpous mosses that occur in base-rich fens, become more prominent, including *Campylium stellatum*, *Drepanocladus revolvens* and the now rare *Tomentypnum nitens* . A notable species in these intermediate base-rich fens is *Hamatocaulis vernicosus* (see Figure F1), a Nationally Scarce moss that is one of three English bryophytes included in the EU Habitats Directive.

In strongly base-rich rich fens *Sphagnum* mosses are generally absent, whilst the brown mosses increase in abundance and diversity, with *Palustriella commutata* sometimes highly prominent and other species such as *Ctenidium molluscum* and *Drepanocladus cossonii* frequent. Other characteristic bryophytes in rich fens include the mosses *Rhizomnium pseudopunctatum*, *Plagiomnium elatum* and *Philonotis calcarea*, and the liverworts *Aneura pinguis* and *Pellia endiviifolia*. The Critically Endangered Section 41 liverwort *Leiocolea rutheana* occurs in rich fens at a very small number of sites.

The restoration of natural processes on areas of fen and bog habitats is in many cases likely to be beneficial for bryophytes, for example, by restoring natural flows of base-rich water by removing pipes from springheads, or by re-instating extensive grazing by hardy cattle or ponies helps keep the vegetation structure open, creates suitable microhabitats, and prevents the bryophytes from being overwhelmed by the build-up of litter. Eutrophication of bogs and fens is a considerable threat to bryophytes as well as to many other plants and animals that live there, and the prevention of the influx of nutrients from surrounding farmland and other pollution sources will be of considerable benefit. Similarly the maintenance of naturally high water tables will greatly benefit fen and bog bryophytes and other species. However, in the case of the rarer species, including those listed within Section 41, care will need to be taken within individual sites to ensure that large-scale management actions do not have a negative effect on species that may be restricted to very small areas of habitat.

F6.3 Birds

A range of Section 41 bird species use fen and bog habitats for at least part of their life cycle (Table F6). Although fens and bogs generally support a low diversity of breeding birds they are particularly important for some of our scarcest wetland species. Indeed the destruction of such habitats, in particular the fens of lowland England, resulted in the near loss of breeding Bitterns (*Botaurus stellaris*) in Britain and the extinction of breeding Spoonbills (*Platalea leucorodia*). Lowland mires were also of historic importance for breeding Curlew (*Numenius arquata*) and Snipe (*Gallinago gallinago*), which have now declined greatly in lowland areas following the loss and degradation of the mire habitat.

Table F6. Section 41 bird species strongly associated with heathland habitats. (B = breeding, NB = non-breeding)

Species	Breeding status	Wetland habitat
Bittern	B & NB	Reedbed
Hen Harrier	NB	Fen, reedbed (NB), Upland blanket bog
Black Grouse	B & NB	Upland blanket bog
Red Grouse	B & NB	Upland blanket bog
Curlew	B	Upland blanket bog
Nightjar	B	Raised bog
Grasshopper Warbler	B	Fen
Savi’s Warbler	B	Reedbed
Aquatic Warbler	NB	Reedbed, fen
Willow Tit	B & NB	Wet Woodland
Reed bunting	B & NB	Fen

Many Section 41 species associated with fens and bogs are dependent on reedbeds and tall fens, particularly extensive areas of undisturbed reedbed in the case of breeding Bittern, overwintering Hen Harriers (*Circus cyaneus*) and other scarce species such as breeding Common Crane (*Grus grus*) and Spotted Crake (*Porzana porzana*). Other species can use smaller areas of reed within a broader landscape of wetland habitats, such as Savi’s Warbler (*Locustella luscinioides*) and non-Section 41 species such as Marsh Harrier (*Circus aeruginosus*). Grasshopper Warblers (*Locustella naevia*) are associated with a wide range of tall vegetation and scattered scrub, including fen and bog habitats with some scattered scrub such a bog myrtle. Other scarce breeders such the Woodlark (*Lullula arborea*) and Tree Pipit (*Anthus trivialis*) were also associated with such habitats, although they are now more reliant on areas of dry heath. Although commonly associated with reedbeds, passage Aquatic Warbler (*Acrocephalus paludicola*) also require adjacent sedge-dominated areas for foraging. Willow Tits (*Poecile montanus*) use wetland scrub and woodland with a good abundance of rotting wood for the creation of nesting holes, while the very rare Spoonbill and scarce Little Egret (*Egretta garzetta*) will use such habitats for nesting in trees.

Nightjars (*Caprimulgus europaeus*)   require a mosaic of habitats, often nesting on dry heath or in scrub and woodland, and foraging for invertebrates over adjacent wetland habitats. At least one area of raised mires supports nationally important numbers of breeding nightjars (Thorne and Hatfield Moors). Extensive areas of inaccessible wetland habitats are particularly important for shy breeding species sensitive to disturbance such as Bittern, Crane and the recently colonised Great White Egret (*Ardea alba*).

Upland blanket bogs with a good cover of dwarf shrubs support both breeding and non-breeding Red Grouse (*Lagopus lagopus scotica*) and Black Grouse (*Lyrurus tetrix*) and, during the summer, important numbers of breeding Curlew, Golden Plover (*Pluvialis apricaria*) and Dunlin (*Calidris alpina*). Whilst many upland blanket bogs retain significant value for such species, historical drainage, over-grazing and burning have reduced habitat suitability for breeding birds. Extensive areas of undisturbed bog are also provide important breeding habitat for Hen Harriers, although few areas are occupied by the species in upland England at present.

Natural processes which favour a wide range of hydrological conditions and vegetation structures will favour a higher diversity of breeding bird species. Thus, although continuous blocks of inundated reedbed and fen support breeding bitterns and spotted crakes, many other species require some additional structural diversity, for example in drier peripheral areas where some scrub and open woodland development can favour Cranes and Willow Tits. Although some vegetation succession to scrub or woodland might be unsuitable for many wetland plants and other species, it can be essential for some breeding bird species. In some circumstance less variable water levels can be beneficial. For example, relatively stable water levels are particularly important for nesting Bitterns which depend on permanent but stable inundation of reedbeds for foraging and safety of eggs and chicks from predators, but cannot withstand significant fluctuations in water level during the breeding season.

Unsustainable activities which reduce the value of wetland areas to birds include peat-cutting, moor-gripping, lowland drainage by ditches and drains and the deepening and straightening of rivers, all of which can reduce habitat extent and/or suitability for wetland birds. In the uplands, overgrazing and intensive moor-burning can also result in the loss of suitable habitat for breeding Hen Harrier, Red and Black Grouse, Curlew and other upland species.

The re-establishment of extensive wetland habitats in lowland floodplains, creating large-scale mosaics of inundated reedbeds, fens, pools, areas of shorter vegetation along with scattered scrub and wet woodland, will benefit a wide range of species during both the breeding and non-breeding seasons. Similarly, restoring the natural hydrology and vegetation cover of upland wetlands, including blanket bog, will provide suitable habitat for several declining and threatened upland birds.

F6.4 Mammals

Although there are no mammal species exclusive to fens in the UK, many different animals take advantage of fens for food and shelter, particularly where the fen is associated with open water and other semi-natural habitats.

Water voles (*Arvicola terrestris*) burrow in the earth banks of all kinds of slow-moving rivers, streams and ditches frequently associated with fen, swamp and wet grassland. Their distribution and population is decreasing rapidly due to loss of suitable habitat, especially in England and they are now vulnerable to extinction. Water voles depend on clean, fresh water and un-shaded riparian vegetation, feeding on grasses and other plant material.

Water shrews (*Neomys fodiens*) and harvest mice (*Micromys minuta*) are also found along the banks of watercourses and open water, and in reedbeds, marsh and other fen habitats. As with so many wetland specialists, the populations and distribution of all three of these species is patchy having suffered significantly because of habitat loss and fragmentation, pollution and disturbance.

Otters (*Lutra lutra*) were once widespread throughout the UK, but declined rapidly in the late 20th century, becoming increasingly restricted to the north and west of the country at that time. The decline of otters across southern England and Wales was primarily due to the build-up of persistent organo-chlorine pesticides which affected their ability to breed. This decline has now largely been halted since these chemicals were banned and otters are once more becoming widespread throughout the UK. Otters are mainly found in still and running freshwater systems and along the coast, especially in Scotland, but associated habitats including fens and swamps are important for breeding, feeding and resting as the tall vegetation provides cover.

Bat species associated with wetland habitats include pipistrelle bats (*Pipistrellus* spp.) noctule bats (*Nyctalus noctula*), brown long-eared bat (*Plecotus auritus*) and Daubenton's bat (*Myotis daubentonii*). Although the latter are particularly associated with aquatic habitats and some of the other species noted may be more generic in their habitat requirements, they all occur in fens and reflect the mosaic of habitats within the wetland and its surroundings.

Restoration of more naturally functioning habitat mosaics containing fen and bog, along with open water and terrestrial habitats, would provide the habitat needed by these mammal species to thrive, However, they do exploit modified habitats such as ditches, which may be affected by restoration works. Restoration therefore needs to be done carefully and in a staged manner to ensure persistence of existing populations throughout and after the works. It is acknowledged that populations of these species could be lower after restoration, but it is expected that the benefits to wider species assemblage overall would outweigh the impact of a reduction in population numbers. Greater connectivity of habitat that is able to support a much wider assemblage of species overall should ensure populations of these species are stable and in line with the carrying capacity of the natural ecosystem.

F6.5 Amphibians and reptiles

Amphibians and water-related reptiles are strongly associated with mire habitats, although amphibian species cannot tolerate the higher acidities found in the waters of some bog habitats. For all amphibians, as well as the grass snake *Natrix natrix,* the close proximity of semi-natural wetland and mixed terrestrial vegetation to open freshwater is critical, providing a combination of sites for breeding, feeding, shelter and over-wintering. The fine-scale mosaic of naturally functioning wetland mosaics contains the pools and ponds necessary for amphibian breeding, whilst streams, rivers and lakes provide further opportunities.

Most species can live quite happily in artificial open freshwater habitats, but a lack of associated wetland habitat reduces landscape suitability in terms of opportunities for feeding, shelter, movement and over-wintering. Individual waterbodies are less important to amphibian and reptile species than networks of adjacent waterbodies within associated wetland and terrestrial habitat. This is because they occur in metapopulations where individual populations are connected by dispersing individuals. This maintains the genetic integrity of all the individual populations and generates recolonization in instances where a population is eliminated (which can happen for various reasons, natural or man-made). Metapopulations increase the ecological resilience of species, but can only exist in areas with multiple suitable habitats and free connectivity between them. Metapopulations are particularly important for great crested newt (*Triturus cristatus*).

Naturally functioning mosaics of water, wetland and terrestrial habitats, with diverse vegetation from open vegetation to scrub and woodland, provide the perfect landscape for amphibian and reptile metapopulations, particularly where a range of waterbody types occurs (ephemeral, permanent, small and large, with and without fish populations) to cater for the widest range of amphibian and reptile species possible and to provide ecological resilience.

F7. Key messages

1. Improving natural function across all five natural process elements is the principal means by which fen and bog habitats and their characteristic assemblages need to be restored, and is a critical activity for climate change adaptation in these ecosystems.

2. The needs of individual species (including priority species) are well-catered for by natural ecosystem function, as long as a dynamic and flexible perspective is taken of their habitat niches.

3. There are some potential conflicts with other habitats and their associated species, but many of these are resolvable through a wider appreciation of natural ecosystem function and a large-scale approach to habitat and species conservation.

4. Some biodiversity conflicts with other habitats will be difficult to resolve (e.g. where rare species are threatened and more naturally functioning niches cannot be restored), and these will act as a constraint to restoring natural fen and bog habitat function.

5. There are considerable socio-economic constraints that need to be considered when targeting action to restore natural function and in developing restoration plans.

6. There are strong synergies with the objectives of the Water Framework Directive in relation to restoring natural ecosystem function, and strong synergies with a range of ecosystem services (e.g. flood risk management).

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